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Parallaxes and Proper Motions of Prototypes of Astrophysically Interesting Classes of Stars. I. R Coronae Borealis Variables^{1,2}

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ABSTRACT. *Hipparcos* data were obtained under the 1982 announcement of opportunity for the seven brightest R CrB stars then known. None of the parallax measurements is different from zero in a statistically significant way, though most of the proper motions are. The body of the data nevertheless suggests that the stars belong to two rather different populations in either luminosity, kinematics, or both. The best-known stars (R CrB itself, RY Sgr, and perhaps others) probably are the very luminous, $M_V = -4$ to -5 , objects they are generally accused of being, but others may belong to a fainter class for which there is some independent evidence among stars in the Large Magellanic Cloud. Alternatively, or in addition, the apparently fainter stars may belong to a higher-velocity population that we have had rather bad luck in sampling. Of two rash assumptions, the one that all seven stars are at the same distance of 1200 pc leads to a velocity ellipsoid $\langle U^2 \rangle^{1/2}$, $\langle V^2 \rangle^{1/2}$, $\langle W^2 \rangle^{1/2} = 41, 30, 35 \text{ km s}^{-1}$, which is “not inconsistent” with values typical of (other) old disk populations, like carbon stars, long period variables, and planetary nebulae. The seemingly less rash assumption that all stars have $M_V = -4.5$ leads to $\langle U^2 \rangle^{1/2}$, $\langle V^2 \rangle^{1/2}$, $\langle W^2 \rangle^{1/2} = 52, 60, \text{ and } 104 \text{ km s}^{-1}$, which resembles no known stellar population, at least not in our galaxy.

1. INTRODUCTION

The R Coronae Borealis variables are a rather exclusive set of about 40 stars characterized by (a) a morbid propensity to sudden, unpredictable fading by many magnitudes (Pigott 1797); (b) roughly periodic variability of very small amplitude, considering the long periods (Jacchia 1933), which can be modeled with linear and nonlinear pulsation codes of the usual sort (Trimble 1972); and (c) atmospheres greatly depleted in hydrogen and enhanced in carbon and helium (Berman 1935; Myerscough and McDowell 1966). Clayton (1996) has provided an excellent review, with more recent references to these phenomena and others. Discussions of atmospheric composition (Lambert 1986; Jeffrey and Heber 1993; Lambert and Rao 1994; Rao and Lambert 1996; Asplund et al. 1997a, b) are based on model atmospheres where 90% or more of the atoms are helium. Not that strong helium lines are seen in these cool stars, but, in the virtual absence of hydrogen, there don't seem to be many alternatives.

None of the stars is close enough to have a meaningful ground-based parallax, and information about their luminosities and masses comes from three examples in the Large Magellanic Cloud (Feast 1972), supplemented by

space motions, galactic distribution, and atmospheric modeling. These latter are, at least, consistent with $M_V = -4$ to -5 as required by the LMC stars. It should, however, be noted that most of the discussions (Drilling 1986; Lawson and Cottrell 1990; Lawson et al. 1990; Lambert and Rao 1994) have more or less begun by assuming the absolute magnitude, so that consistency is all that can be expected. The population type has been variously described as bulge (though some of the stars are outside the solar circle) or old disk.

Motivated by this dearth of data, the senior author included in a 1982 application with G. H. Herbig to the *Hipparcos* Programme Selection Committee the seven brightest R CrB stars then known. The flavor of the process can be recovered by noting that one was allowed to submit one's observing list on either magnetic tape or punched cards. The seven stars, all of which survived into the *Hipparcos Input Catalogue* (ESA 1992) were (in rough order of decreasing apparent brightness and fame): R CrB, RY Sgr, XX Cam, S Aps, UW Cen, V CrA, and SU Tau. V854 Cen, though sometimes as bright as 7th mag, has spent most of the 20th century at 10–13th mag or fainter, and so was not recognized as an R CrB until 1986 (McNaught and Dawes 1986). Nor does it appear in the *Input Catalogue*, though it presumably has a reasonable chance of turning up in the *Tycho Catalogue* (ESA 1997a).

¹Based on data from the ESA *Hipparcos* astrometry satellite.

²Dedicated to the memory of Louis Berman (1903–1997) and Valerie P. Myerscough (1941–80).

TABLE 1
Observed and Derived Astrometric Quantities for Seven R Coronae Borealis Variables

Number Name	π^a Sigma	μ (RA) ^b Sigma	μ (δ) ^b Sigma	d^c Range	m^d Range	M_v^e Limit	V_r^f Limit	$B - V^g$ A_v	l^h b	d (vel) ⁱ d (lum)	V_r^j
77442 R CrB	+0.54 0.72	-2.10 0.37	-11.52 0.49	1852 749-∞	5.8 5.9-6.4	-5.5 -3.7	103 41	0.60 0.15	45 +5	3610 1070	+21 v
94730 RY Sgr	+0.36 1.12	+10.33 1.15	-0.41 0.62	2778 676-∞	6.5 6.2-7.0	-5.7 -2.6	136 29	0.69 0.39	4 -19	4100 1320	-22 v
19340 XX Cam	-1.04 0.90	+1.09 0.74	-3.46 0.71	---- ≥ 1316	7.3 7.4-7.5	---- -3.3	--- 17	0.82 0.81	150 +1	11600 1580	+16
74179 S Aps	-0.89 1.56	-5.45 1.37	-0.76 1.68	---- ≥ 448	9.6 9.7-10.5	---- +1.3	--- 9	1.25 0.15	313 -12	7670 6166	-78
62071 UW Cen	+1.27 1.36	-7.87 3.26	-12.64 3.89	787 245-∞	9.6 9.6-12.6	+0.1 +2.6	56 11	0.75 0.96	302 +8	2830 4250	-29
92207 V CrA	+1.18 2.77	-6.03 4.12	-4.83 2.65	847 253-∞	9.4 10.0-10.9	-0.2 +2.4	31 4	0.62 0.42	358 -16	5490 4880	-9 v
27465 SU Tau	+3.32 5.24	+3.57 6.16	+1.17 3.28	301 117-∞	9.5 10.3-10.5	+2.1 +4.2	5 0	1.10 1.50	189 -4	11200 3160	+37
Mean absolute values		5.12	4.97								30.0

Notes to TABLE 1

^aParallax and standard error in milli-arcsec from *Hipparcos*.

^bProper motions (right ascension and declination) and standard errors in milli-arcsec per year from *Hipparcos*.

^cDistance in parsecs corresponding to parallax, one-sigma range, or two-sigma limit, where parallax is negative.

^dObserved apparent magnitude, roughly V (outside fading episodes) from Clayton (1996) or AAVSO (Mattei 1997) and range during the *Hipparcos* observing period (their magnitude system).

^eAbsolute magnitude corresponding to parallax if no absorption; faint limit (one or two sigma, as for distance).

^fCentral value of transverse velocity for parallax and proper motion as given; lower limit (one sigma on proper motion, one or two sigma on parallax as for distance).

^gObserved color index (outside fading, Johnson colors) from Asplund et al. (1997a), sources cited by Clayton (1996), and *Hipparcos*. Expected value of A_v , assuming the intrinsic $(B - V)$ colors given by Asplund et al. (1997a) and $A_v = 3E(B - V)$.

^hGalactic latitude and longitude, nearest degree.

ⁱDistance at which transverse velocity would be 200 km s⁻¹; distance at which $M_v = -4.5$, allowing for A_v as shown.

^jRadial velocity, km s⁻¹, from the compilation of Drilling (1986) and from an unpublished set of observations by Herbig (1997). Since most R CrB's are pulsators, probably all the radial velocities are variable; v indicates a central value where some information about the range is available.

This paper presents what we have been able to extract from the *Hipparcos* measurements of these R CrB stars. Results for 14 other stars of five different types will be presented elsewhere (though we are greatly saddened that our sample of cataclysmic variables is lacking SS Cyg, because the wrong star was observed).

2. RESULTS

Table 1 and its countably infinite number of footnotes present the relevant portions of the *Hipparcos* astrometric data, precisely as we received them, and as they are supposed to appear in the *Catalogue* (ESA 1997b), supplemented by apparent magnitude, color, radial velocity, and other information from the sources indicated in the footnotes. The stars are listed in the same order as they were in the original proposal, from bright and well known to faint and obscure. The first point to be made, loud and clear, is

that *none* of the parallaxes is significantly different from zero, at even the one-sigma level, and two are in fact negative. Five of the seven proper motions (all but V CrA and SU Tau, for which the errors are large because they are faint), on the other hand, differ from zero by three times the standard error or more.

Under the circumstances, a reasonable astronomer (for instance the 1982 co-proposer) would conclude that the most we could hope for is some approximation to a statistical parallax from the proper motions and radial velocities, with the reservation that the number of stars is not large enough even for that. It is actually the same as the number of galactic Cepheids from which Shapley originally calibrated his globular cluster distance scale (which was, of course, wrong by about a factor two). Nor are the stars as widely scattered on the sky or as tightly clustered in apparent magnitude as one would wish for the purpose.

The last line of the Table has mean absolute values of μ_α , μ_δ , and V_r . The two corresponding mean distances (from $V_r = 4.74 \mu d$) are 1226 and 1286 pc. Attempting to rotate to the statistically independent components of proper motion, tau and epsilon, requires (given the small and ill-placed sample) assuming some value of the solar motion, and so leads to an even less reliable result. For comparison, the mean of the nominally positive parallaxes is 1.33 mas ($d = 750$ pc), or the mean of the five distances is 1313 pc. The conclusion that these stars are at least a kiloparsec from us does not seem excessively overconfident.

It was a closer look at UW Cen that suggested that the three stars at the bottom of the Table might not be the same sort of beast as the three at the top. If $M_v = -4.5$, then UW Cen is about 4250 pc from us (after allowing for absorption), and the most likely transverse velocity is 300 km s^{-1} (with a one-sigma lower limit of 200 km s^{-1}), headed more or less directly toward the galactic disk from a present position 590 pc above it. This is not impossible. VZ Sgr, an R CrB at $l \approx 30^\circ$, $b \approx -8^\circ$ (but at $V = 11.8$ too faint to have made the *Input Catalogue*) has a radial velocity of $+234 \text{ km s}^{-1}$ in an unpublished dataset (Herbig 1997), though this will project largely into the galactic plane rather than perpendicular to it.

Not impossible, but perhaps a little unlikely. And we would like to suggest, very tentatively, that UW Cen, V CrA, and SU Tau may belong to a class of hydrogen-depleted carbon stars whose absolute magnitudes are considerably fainter than $M_v = -5$. S Aps, at $T_e = 4000$ K (Milone 1990, Asplund et al. 1997a), is intrinsically much cooler and redder than the other six stars, and must also be either very distant and quite fast moving or fairly faint. It is worth noting that the MACHO project (Alcock et al. 1996; Clayton 1997) is beginning to find R CrB stars in the LMC that are (at $M_v = -3.4$ and -3.5 for the first two reported) a magnitude or more fainter than the usually accepted range.

It is also possible that we are (instead or in addition) sampling two different kinematic populations (Feast 1997). The velocity ellipsoid (Schwarzschild 1907, 1908; Mihalas and Binney 1981) is one way of looking at this. Let's try two extremes. First, if we assume that all the stars are 1200 pc away, then the three apparently brightest will have absolute magnitudes of -4 to -5 , and the four faintest -1 to -2.5 . With this same assumption, the velocity ellipsoid (neglecting differential rotation) has components $\langle U^2 \rangle^{1/2}$, $\langle V^2 \rangle^{1/2}$, $\langle W^2 \rangle^{1/2} = 41, 30, 35 \text{ km s}^{-1}$, with very sizable statistical error bars, let alone systematic ones. The numbers are, however, in the general range found for old disk populations like carbon stars, planetary nebulae, long period variables, and short-period RR Lyrae stars (Mihalas and Binney 1981 and many other authorities). The other extreme assumption, that all seven stars have $M_v = -4.5$, leads to a velocity ellipsoid (again neglecting differential rotation) $\langle U^2 \rangle^{1/2}$, $\langle V^2 \rangle^{1/2}$, $\langle W^2 \rangle^{1/2} = 52, 60, 104 \text{ km s}^{-1}$, which resembles no known stellar population, at least in our galaxy.

Can theoretical confirmation help us to believe one form or another of this observation? Not really. Iben, Tutukov,

and Yungelson (1996) indeed suggest two separate evolutionary scenarios to form R Coronae Borealis and related stars. One involves considerable mass loss and a last helium flash in single stars, the other mergers of close pairs of highly evolved ones. But the authors have started with the assumption that their goal is to produce stars of $10^4 L_\odot$ from a given parent population, and neither scenario actually does a very good job of reproducing the known surface abundances of R CrB's. Nor do they consider the possibility of enhanced mixing as a formation process. Rozenbush (1981, 1982) long ago suggested the existence of fainter R CrB's on semi-empirical grounds.

Scenarios connecting R CrB stars with the last helium flash of a star already well on its way to becoming the nucleus of a planetary nebula have recently become popular because of comparisons drawn with the behavior of FG Sge (Herbig and Boyarchuk 1968; Arkhipova and Esipov 1996; Stone, Kraft, and Prosser 1993), V605 Aquilae (Lundmark 1921; Herbig 1958; Bond et al. 1993), and Sakurai's object, V4334 Sgr (Asplund et al. 1997b). The three stars are not all at the same stage in evolving toward R CrB's (if that is what they are doing). FG Sge is rich in carbon and s-process elements and has experienced at least one unprecedented fading, but is not known to be particularly hydrogen-poor. V605 Aql brightened in 1918–24 and has remained faint since. Its spectrum was of type R but has not been subjected to modern analysis. And Sakurai's object is rapidly becoming carbon rich and hydrogen poor after a rapid gallop across the HR diagram similar to that of FG Sge, but has not yet shown any major fading episodes. All three are surrounded by faint nebulosity. If observational selection effects for finding these possible progenitors are the same as for finding R CrB's, then three of the former in a century compared to 40 of the latter implies a lifetime of 1300 years, which is perhaps a bit short, though not intolerably so, given the very small numbers involved.

3. LOOKING AHEAD

The *Hipparcos Input Catalogue* (ESA 1992) contains five additional R Coronae Borealis variables, Y Mus, RT Nor, RS Tel, SV Sge, and U Aqr, all but RS Tel ($V = 9.3$) nominally a good deal fainter than the stars considered here. It seems somewhat improbable that any will have statistically significant parallaxes, unless they are intrinsically very faint. There is, on the other hand, a good chance of additional meaningful proper motions, leading to an improved value of statistical parallax (at least four have good radial velocities), and, if any of these are large, further insight into the real range of absolute magnitudes and kinematic properties of stars subject to sudden fadings of the R CrB type. Adding in the expected sample of hydrogen-deficient stars that are not known to fade might also make sense. Cottrell and Lawson (1997) have done roughly this, and we anxiously await their results.

Finally, one is tempted to say with Rutherford, "Don't do statistics. Do a better experiment." This will not be possible for a very long time.

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